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T. S. NEUMAN

K. MOSER

R. PRUETT

REPORT NO. 79-23 ✓

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Heart Rate and Aerobic Capacity in Individuals
Engaged in Underwater Activities *

T. S. Neuman ¹
K. Moser ²
R. Pruett ³

¹ Naval Health Research Center
P. O. Box 85122
San Diego, California 92138

² University of California, San Diego
School of Medicine
San Diego, California 92093

³ Submarine Development Group ONE
San Diego, California 92132

* This research was supported by the Naval Medical Research and Development
Command, Department of the Navy, under research Work Unit M0099PN001-3125. The
views presented in this paper are those of the authors. No endorsement
by the Department of the Navy has been given or should be inferred.

Report No. 79-23.

Accession For	
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ABSTRACT

Diving activities have been shown to be dangerous to individuals in poor physical condition. Therefore, to increase diving safety, a simple non-invasive method to predict aerobic capacity would be useful. Among the many methods used to estimate aerobic capacity based upon submaximal exercise testing, the most widely used - the Astrand-Ryhming nomogram - has never been validated in the diving population. Twenty-seven Naval personnel were exercised to their maximal oxygen consumption and this value was compared to the maximal oxygen consumption predicted by the Astrand-Ryhming nomogram.

We demonstrated that, in certain groups of U. S. Naval personnel, the Astrand-Ryhming nomogram appears to underestimate the maximal oxygen consumption. As a result, new methodologies to accurately predict aerobic capacity may need to be developed for individuals engaged in underwater activities.

ACKNOWLEDGEMENT

The authors wish to acknowledge the statistical assistance of Mr. D. Ryman, Naval Health Research Center, and the technical assistance of Ms. B. Sutt, C. Fonzi, M. Belso, and Mr. D. Roy of the University of California at San Diego, San Diego, California.

The U. S. Navy employs individuals in a variety of underwater activities requiring high levels of physical fitness for efficiency and safety. The most recently compiled statistics in the U.S. indicate that poor physical conditioning is a major factor in underwater fatalities (Schenck 1972, 1975, 1976). As a result it would be beneficial to have a simple test to estimate the level of conditioning and to predict maximal work capacity in individuals engaged in underwater activities. Astrand-Ryhmning (1954) proposed a nomogram which was subsequently adjusted for different age groups (Astrand 1960) to predict maximum O_2 consumption from submaximal measures of heart rate (HR). Although that nomogram has been shown to be of value in a number of studies (Coleman 1976, Glassford 1965, Shephard 1966, Teräslinna 1966), questions concerning its validity for all groups have been raised (Rowell 1964, Wyndham 1959). Since divers and other naval personnel involved in underwater activities have not been examined, it is not known whether the nomogram is valid for these groups. The following experiment was undertaken to ascertain whether the Astrand-Ryhmning nomogram is reliable in these individuals and thus provides a rapid and safe method of determining maximal aerobic capacity and, presumably, physical fitness.

METHODS AND MATERIALS

Three groups of naval personnel involved in underwater activities were selected for this study. These groups consisted of volunteers from the diving divisions of Submarine Development Group One (SUBDEVGRUONE), Underwater Demolition Team 11 (UDT-11) and training tank instructors from Basic Underwater Demolition/Seal (BUDS). The members of UDT-11 represent a group of naval personnel that are fit but rather infrequently exposed to pressure or breathholding situations. The first class and

Scuba divers from SUBDEVGRUONE are frequently exposed to immersion and pressure, but should only rarely hold their breath. Training tank instructors at BUDS frequently are immersed and are routinely involved in breathholding activities.

To eliminate the possibility of occult lung disease, routine spirometry was initially performed. This consisted of the measurement of standard flows and volumes: maximal mid expiratory flow (MMEF), forced expiratory volume in 1 second (FEV1), vital capacity (VC), inspiratory reserve volume (IRV), and forced vital capacity (FVC). Functional residual capacity (FRC), residual volume (RV), total lung capacity (TLC), and airway resistance (RAW) were measured in a Collins variable pressure body plethysmograph. All subjects were additionally screened for the presence of any cardiorespiratory symptoms.

Following this evaluation, the subjects completed a regimen of graded exercise (Astrand 1954) on a Collins bicycle ergometer with continuous electrocardiographic monitoring. The subjects (pedalling at 50 cpm) performed at the following workloads in sequence or until they were exhausted: 50, 100, 125, 150, 175, 200, 250, 300, 350, and 400 watts. The subjects exercised for a total of 5 minutes at workloads of 50 through 200 watts and for 3 minutes at 250 to 400 watts. A 15 minute rest interval was allowed between each work period. Expired gases were collected during the last minute of exercise, although gas collections were shortened during the final workload to 30 seconds if necessary (due to large \dot{V}_E). The expired gases were collected using a Collins triple valve and low resistance tubing. The volume of the expired gas was measured in a Tissot bell. $F_{E}CO_2$ and $F_{E}O_2$ were measured on a Goddart NV capnograph and Beckman E_2 oxygen analyzer,

respectively, from aliquots of the mixed expired gas. Verification was accomplished with standard calibration gases and an IL 113 pH and gas analyzer. Measured oxygen consumption including maximum $\dot{V}O_2$ were calculated at STPD. Predicted maximum $\dot{V}O_2$ was determined from the Astrand-Ryhming nomogram. $\dot{V}O_2$ was plotted against \dot{V}_E (oxygen consumption and \dot{V}_E were expressed as liters/min, ml/kg/min, ml/meter/min, and ml/m²/min), and correlation coefficients calculated. Heart rate was expressed as beats per minute and percentage of age adjusted maximum, (calculated both from 220 - age and 210 - .65 times age) (Cotes 1968, Wasserman 1975). Comparisons between the maximum $\dot{V}O_2$ measured and the maximal $\dot{V}O_2$ predicted from the Astrand-Ryhming nomogram were made by the use of one way analysis of variance with unequal N (ANOVA) (Winer 1962). A Z-test between pairs of correlations were used to contrast the correlations between $\dot{V}O_2$ and \dot{V}_E in the three groups. (Both of these methods require a Fischer Z transformation of the correlation coefficient) (Zar 1974).

RESULTS

The preliminary pulmonary function testing revealed that all of the subjects were normal as judged by the measured parameters. There were no statistically significant differences among the three groups and multiple regression analysis did not indicate any combination of factors in the pulmonary function tests that differentiated among the groups. The data from 27 of the 46 individuals studied are presented in Table 1. The data from the remainder of the subjects had to be excluded for the following reasons: (1) the subjects would not exercise to maximum $\dot{V}O_2$ (n=4); (2) maximum $\dot{V}O_2$ could not be predicted

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as nomograms do not exist in that range ($n=5$); (3) individuals were still exercising submaximally with the bicycle at maximum setting ($n=10$).

Table 1 contains the means and standard deviations for the three groups (Divers, UDT, and BUDS) for HR at the maximum achieved $\dot{V}O_2$ (HR at $\dot{V}O_2$ max), maximum measured $\dot{V}O_2$ (measured $\dot{V}O_2$ max), maximum predicted $\dot{V}O_2$ from the Astrand-Ryhming nomogram (AR pred $\dot{V}O_2$ max) and the difference between maximum measured and predicted $\dot{V}O_2$ ($\Delta \dot{V}O_2$ max).

The maximal HR among the three groups was not significantly different. Divers have a significantly lower measured $\dot{V}O_2$ maximum than UDT ($t=2.69$, $p < .05$) and their AR predicted $\dot{V}O_2$ maximum was also significantly lower than the UDT ($t=4.26$, $p < .001$). However, the difference between the divers AR predicted $\dot{V}O_2$ and their measured $\dot{V}O_2$ maximum was not significant. The difference between the measured $\dot{V}O_2$ maximum of the BUDS and UDT was not statistically significant. However, the AR predicted $\dot{V}O_2$ maximum of the BUDS instructors was significantly lower than for the UDT ($t=2.74$, $p < .05$). UDT had a lower difference between measured $\dot{V}O_2$ maximum and AR predicted $\dot{V}O_2$ maximum (t for dependent variables = 3.61, $p = .02$) than the BUDS. It should be noted, that although not statistically different from either BUDS or UDT, the divers $\Delta \dot{V}O_2$ maximum falls midway between the others. Analysis of ventilatory response to exercise (graphs of \dot{V}_E vs. $\dot{V}O_2$) did not reveal any significant differences among the three groups (Fig. 1).

DISCUSSION

The maximal O_2 uptakes obtained in this study are within the range of values reported in previous studies. It is of interest that the UDT and BUDS groups attained measured $\dot{V}O_2$ maximum comparable to the 3.95 ± 0.430 l/min found by Buskirk and Taylor (1957) for young trained subjects

and 4.15 ± 0.360 l/min by Astrand (1952) for Swedish athletes. Similarly the divers attained levels nearly equal to Buskirk and Taylor's (1957), $3.44 \pm .460$ l/min for a group of sedentary students and soldiers 18-29 years old. Additionally, Mitchell et al. (1958) obtained a value of 3.37 ± 0.510 for 15 subjects not actively training. This would indicate that UDT and BUDS groups maintain a higher degree of cardiovascular fitness than do the divers we tested.

Use of the Astrand-Ryhming nomogram for predicting maximum $\dot{V}O_2$ (AR pred $\dot{V}O_2$ max) elicited the surprising result that, while the nomogram accurately predicted the maximal O_2 consumption for the UDT group, it significantly underestimated the true maximum oxygen consumption for the BUDS group. Physical fitness as measured by the actual maximal oxygen consumption is similar for these two groups, and the physical training programs are essentially the same with the exception that the BUDS personnel are involved in frequent immersion and breathholding activities. Finally, the divers who are involved in underwater activities and varying degrees of breathholding and/or skip breathing exhibited a $\Delta \dot{V}O_2$ maximum intermediate to the BUDS and UDT groups but not significantly different from either.

Although the reasons for these differences are not clear, several explanations may be considered. The groups, while generally of similar cross section, were not matched and therefore could not rigorously be controlled for smoking history, diet, and other similar variables. The possibility thus exists that some unknown factor may account for the difference; i.e., a factor promoting increased HR at submaximal effort, thus causing underprediction of maximal oxygen consumption by the nomogram.

Another intriguing possibility is that the increased HR at submaximal exercise may be a physiological adaptation to exercise during chronic breathholding. The ventilatory response to exercise was the same for all groups, thus ventilatory adaptations cannot explain this observation. Differences in conditioning cannot explain the observed differences since the largest error in AR pred. $\dot{V}O_2$ maximum occurred in the BUDS while UDT with comparable measured $\dot{V}O_2$ maximum had the smallest $\Delta \dot{V}O_2$ maximum. Thus we are left without a clear explanation for the observed differences.

SUMMARY

The U. S. Navy employs personnel for a variety of underwater tasks. Fatigue from lack of proper physical conditioning can extend the time requirement for a job and at times jeopardize the completion of a project or compromise safety of the individual diver. Additionally, drowning is the number one cause of death in sport divers and is generally related to poor fitness and training (Schenck 1972, 1975, 1976). It thus becomes clear that it would be valuable to have a simple test to predict physical conditioning. This study indicates that, while the Astrand-Ryhmung nomogram can accurately predict aerobic capacity for some groups of individuals, it cannot accurately predict aerobic capacity in all groups engaged in various underwater activities and may generally underestimate the maximal oxygen consumption of individuals who breathhold.

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TABLE I *

<u>Group</u>	HR at $\dot{V}O_2$ Max		Measured $\dot{V}O_2$ Max		AR Pred. $\dot{V}O_2$ Max		$\Delta \dot{V}O_2$ Max	
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Divers (n=8)	188.8	5.0	3.49	.36	3.15	.46	.34	.52
UDT (n=11)	185.7	5.9	4.11	.44	4.17	.51	.06	.24
BUDS (n=8)	184.7	4.3	3.89	.60	3.41	.46	.47	.35
TOTAL	186.4	5.3	3.85	.52	3.63	.65	.22	.43

* Means and Standard Deviations of three groups for HR at $\dot{V}O_2$ Max, Measured $\dot{V}O_2$ Max, and Predicted $\dot{V}O_2$ Max with comparative statistics.

All values in l/min.

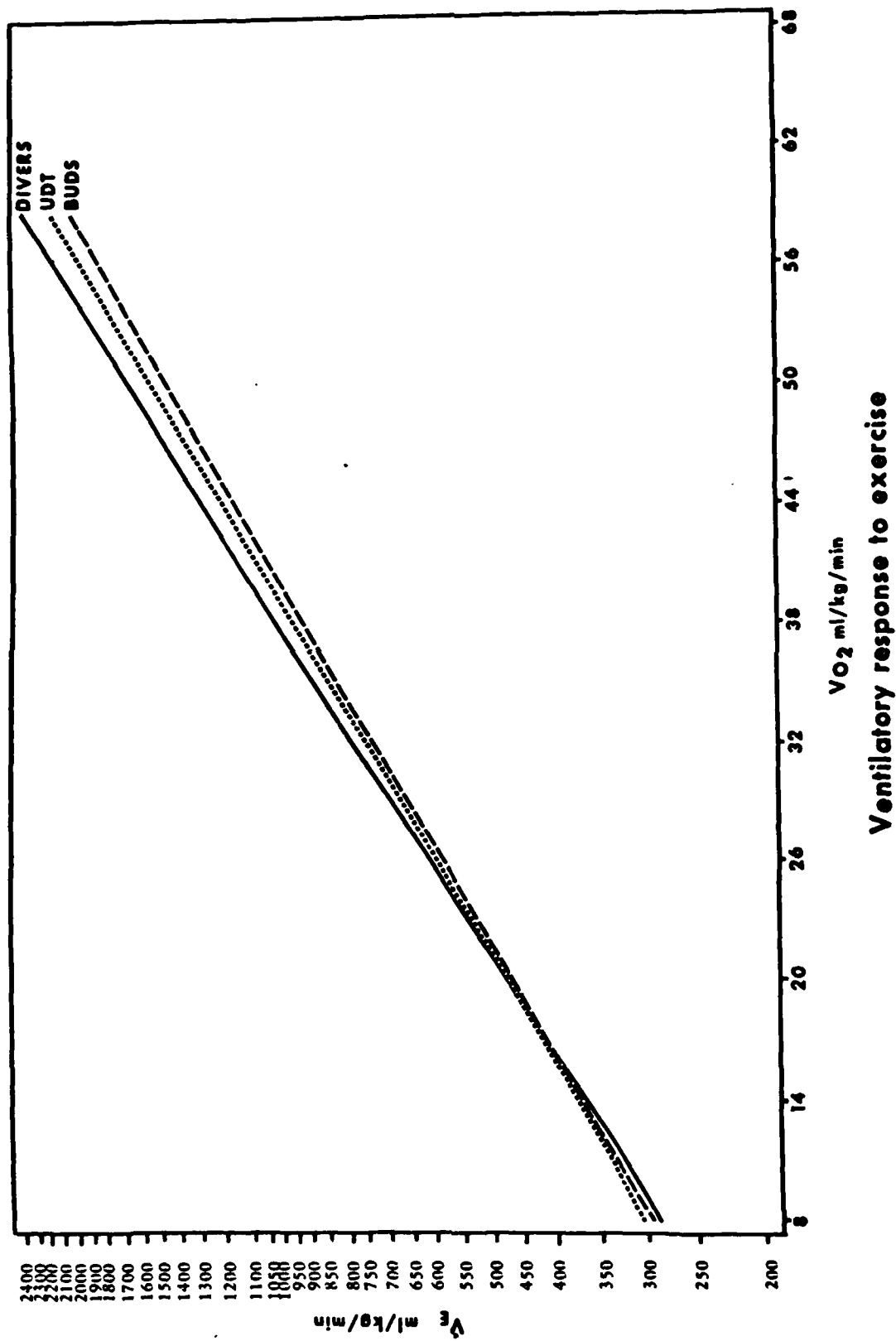


Figure 1. Graph of the ventilatory responses to exercise of the three different study groups.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 79-23	2. GOVT ACCESSION NO. AD-A105387	3. RECIPIENT'S CATALOG NUMBER (4)
4. TITLE (and Subtitle) Heart Rate and Aerobic Capacity in Individuals Engaged in Underwater Activities		5. TYPE OF REPORT & PERIOD COVERED Final rept.
7. AUTHOR(s) T. S. Neuman, K. Moser, & R. Pruett		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Health Research Center P.O. Box 85122 San Diego, CA 92138		8. CONTRACT OR GRANT NUMBER(s) M0099FN
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Medical Research & Development Command Bethesda, MD 20014		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS M0099-PN.001-3125
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Bureau of Medicine & Surgery Department of the Navy Washington, D.C. 20372		12. REPORT DATE July 1979
		13. NUMBER OF PAGES 12
		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. 14 NAV-LTHRSCHC-77-23		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Aerobic Capacity Oxygen Consumption Heart Rate Divers		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (U)....Diving activities have been shown to be dangerous to individuals in poor physical condition. Therefore, to increase diving safety, a simple non-invasive method to predict aerobic capacity would be useful. Among the many methods used to estimate aerobic capacity based upon submaximal exercise testing, the most widely used - the Astrand-Ryhming nomogram - has never been validated in the diving population. Twenty-seven Naval personnel were exercised to their maximal oxygen consumption and this value was compared		

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We demonstrated that, in certain groups of U.S. Naval personnel, the Astrand-Ryhming nomogram appears to underestimate the maximal oxygen consumption. As a result, new methodologies to accurately predict aerobic capacity may need to be developed for individuals engaged in underwater activities.

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